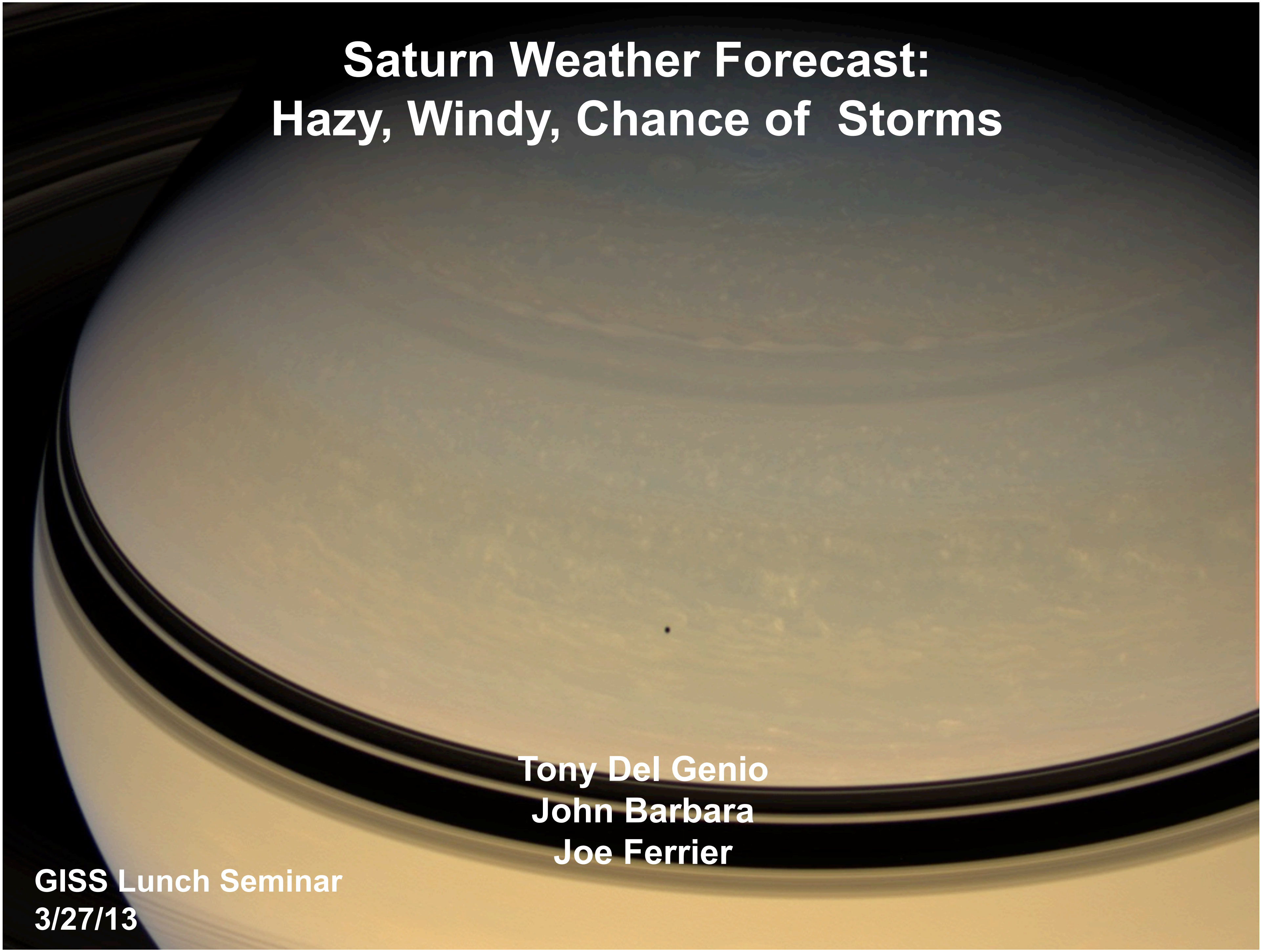
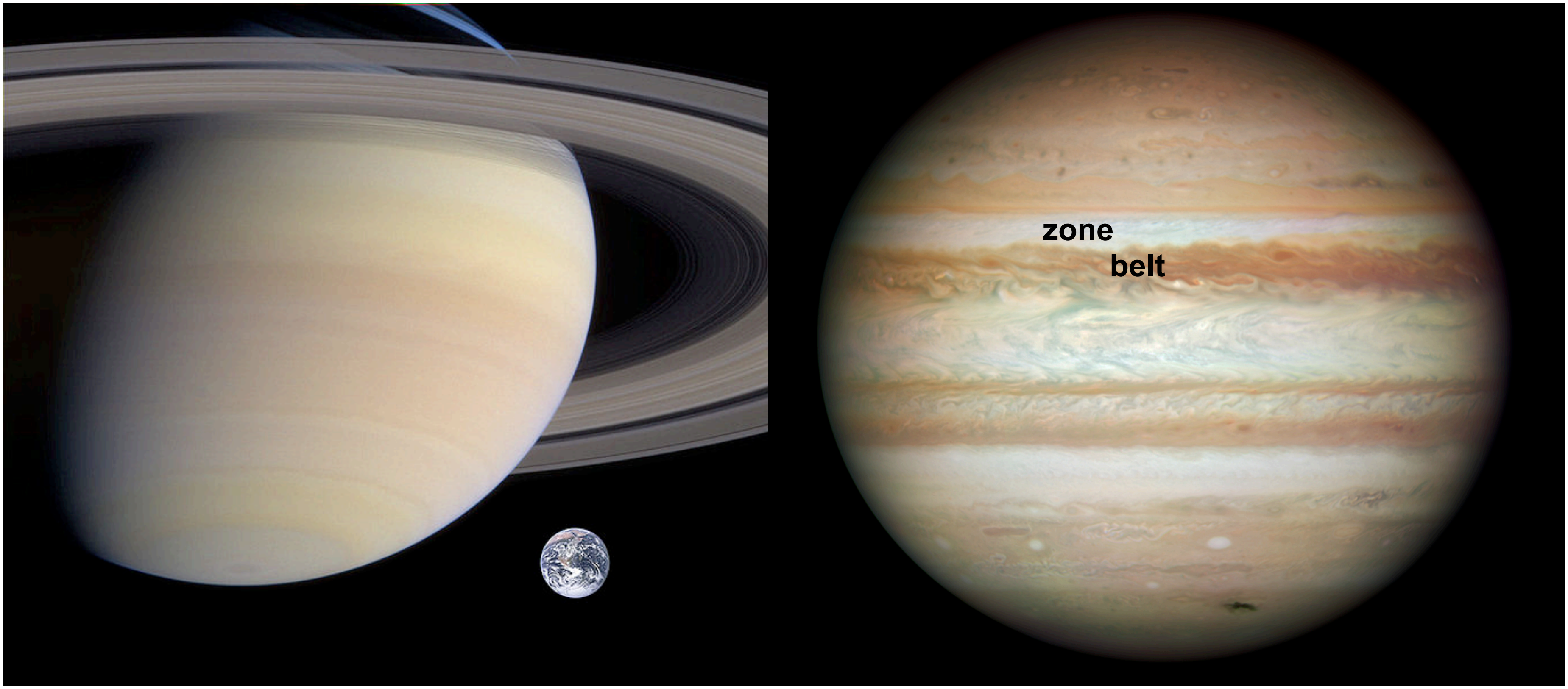
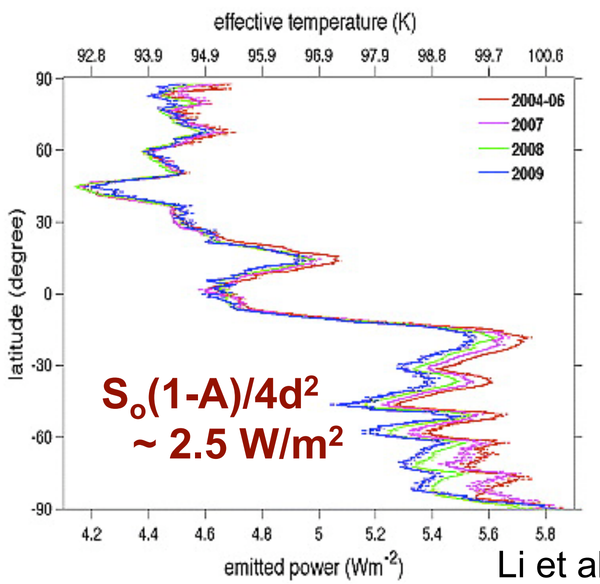

Saturn Weather Forecast:
Hazy, Windy, Chance of Storms
Tony Del Genio
John Barbara
Joe Ferrier
GISS Lunch Seminar
3/27/13





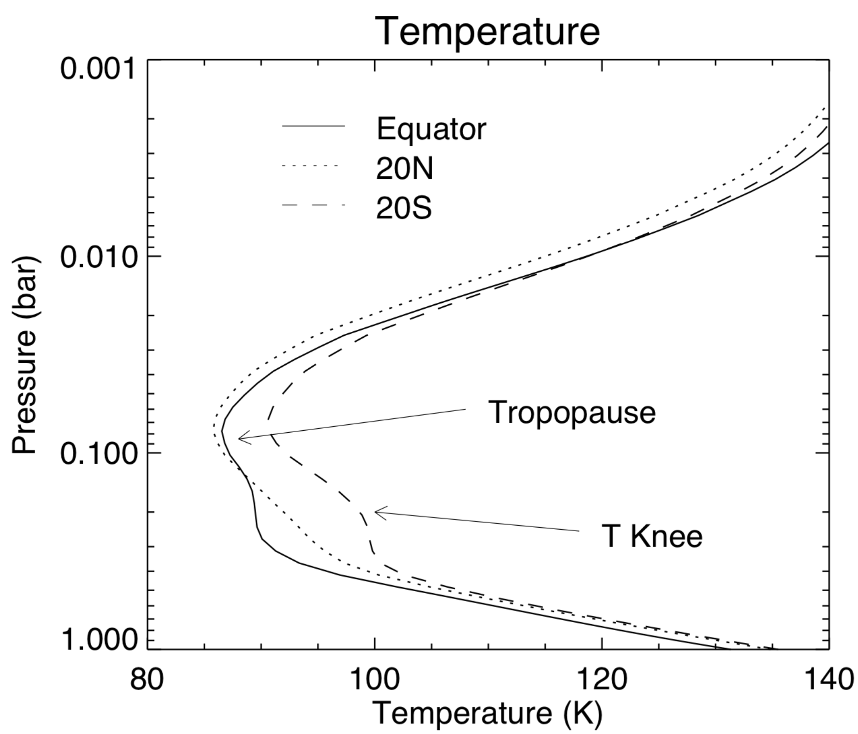
Li et al. (2010)

A few relevant facts about Saturn:

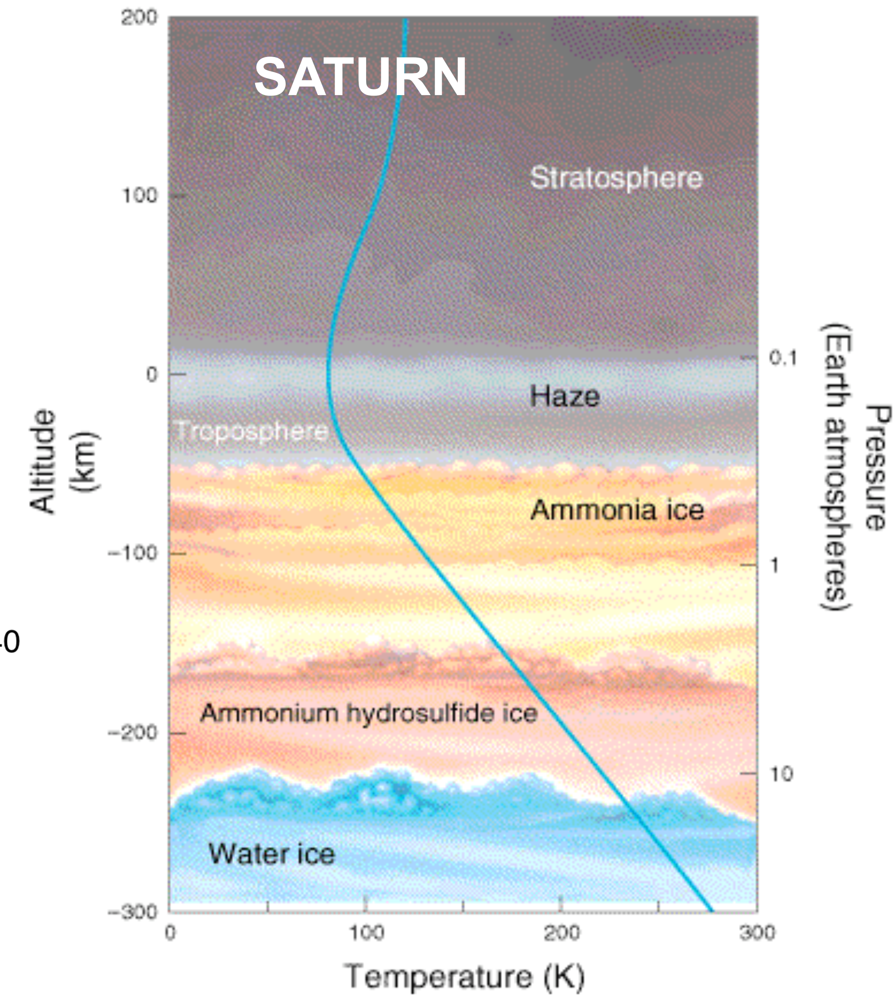
- Much bigger than Earth (H_2, He atmosphere + trace amounts NH_3, H_2O, CH_4, …)
- Much more introverted than cousin Jupiter
- Emits almost twice as much LW as the SW it absorbs, due to internal heat source
- No equator-pole temperature gradient

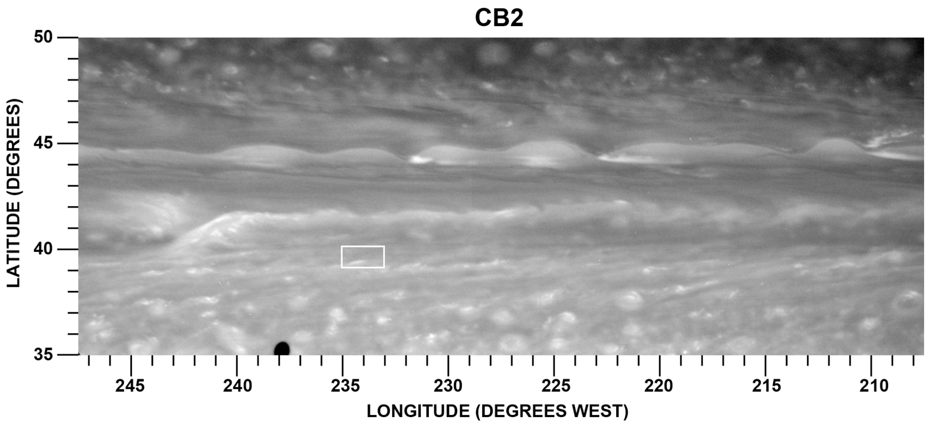
Earth: An observer’s dream	Saturn: An observer’s nightmare
• Partly clear, partly cloudy; can see top to bottom	• Overcast; can’t see below the clouds where action is
• Small – global observing easy	• Big – need to stay far away to see it all
• No rings to get in the way!	• Lots of rings obscure the view
• Strongly forced – phenomena of interest happen often	• Weakly forced – relevant processes occur once in a while
• People who launch radiosondes for “ground truth”	• Saturnians haven’t yet released their sonde data to NASA

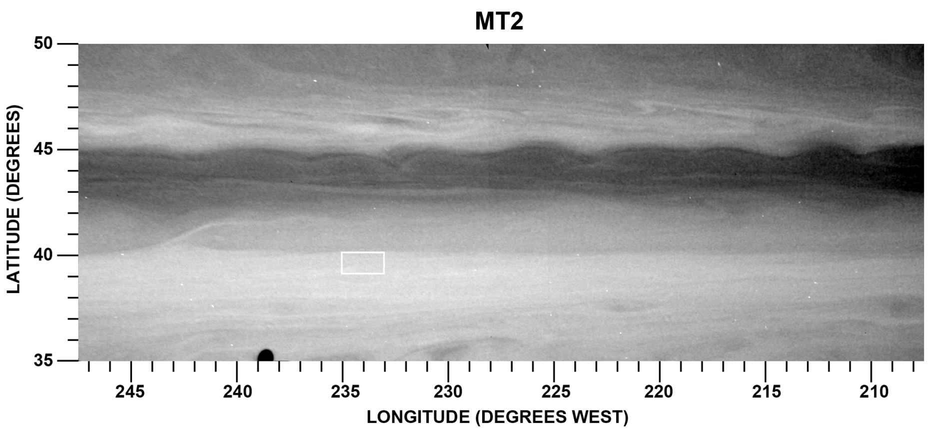
Water clouds buried beneath ammonia and (probably) ammonium hydrosulfide clouds on Saturn, plus optically thick ($\tau \sim 10$) upper tropospheric haze that obscures the weather



Fletcher et al. (2007)

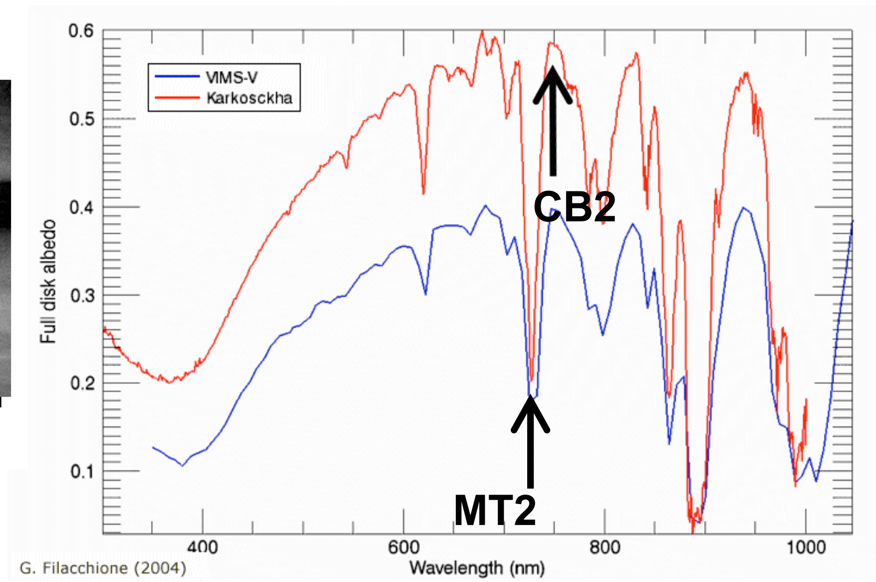


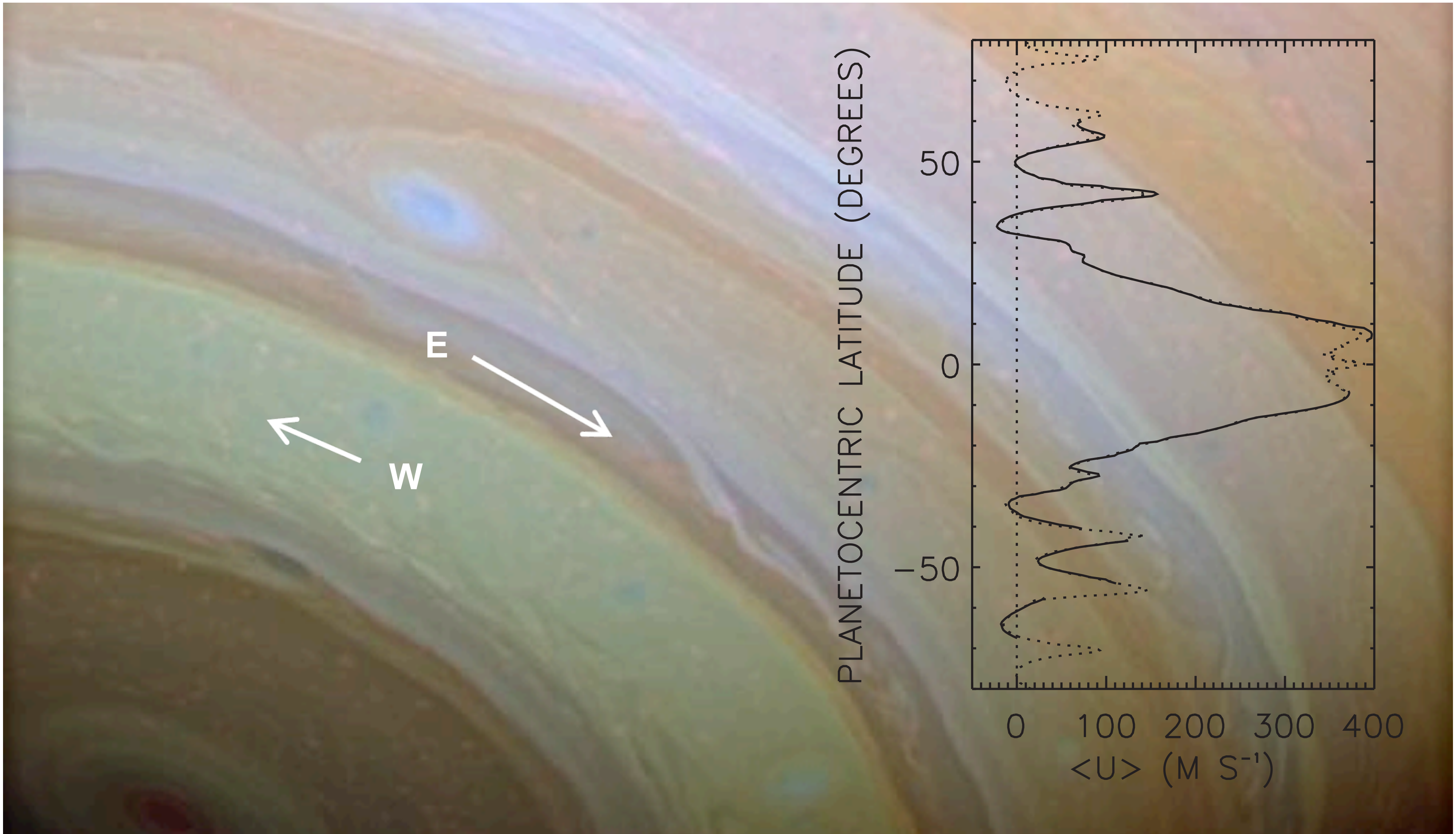




Observing strategy:

- **CB2: Near-IR (750 nm) continuum filter, partly sees through haze, reflected from deeper thicker clouds**
- **MT2: Adjacent (727 nm) CH_4 absorption band, sees to haze level**



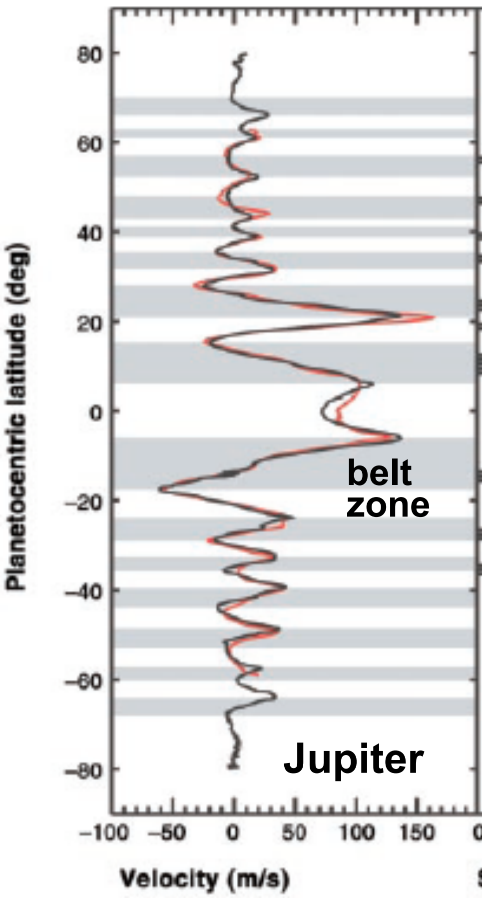


Rapid (10 hr 39 min) rotation produces zonally oriented cloud bands and alternating eastward/westward jets of ~100 m/s, stable for decades, except ~ 400 m/s equatorial jet – what maintains the jets?

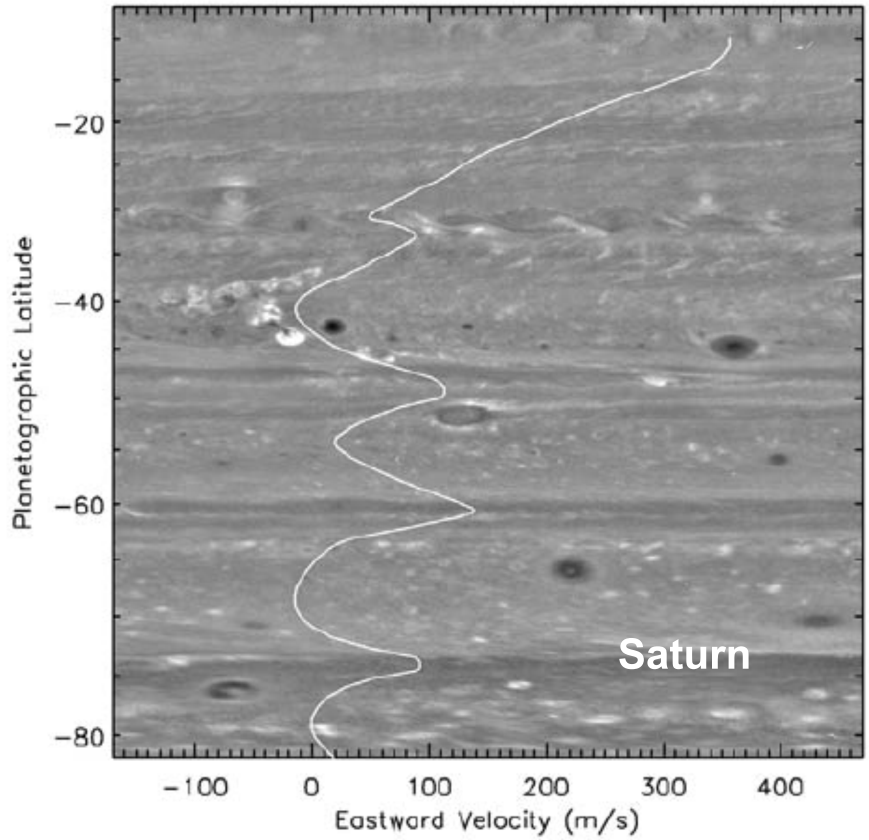
More specifically:

- **Are the jets deep or shallow?**
- **Is the forcing for them deep or shallow?**
- **Driven by radiative heating or the internal heat source?**
- **Instability providing the energy?**
- **What sets the jet latitudinal scale and how does the energy get to that scale?**

Jupiter: zones (bright) → anti-cyclonic shear,
belts (dark) → cyclonic shear
Saturn: More fine structure; if anything,
dark → eastward jets



Porco et al. (2003)



Vasavada et al. (2006)

Fundamental dynamical length scales

Rossby radius of deformation:

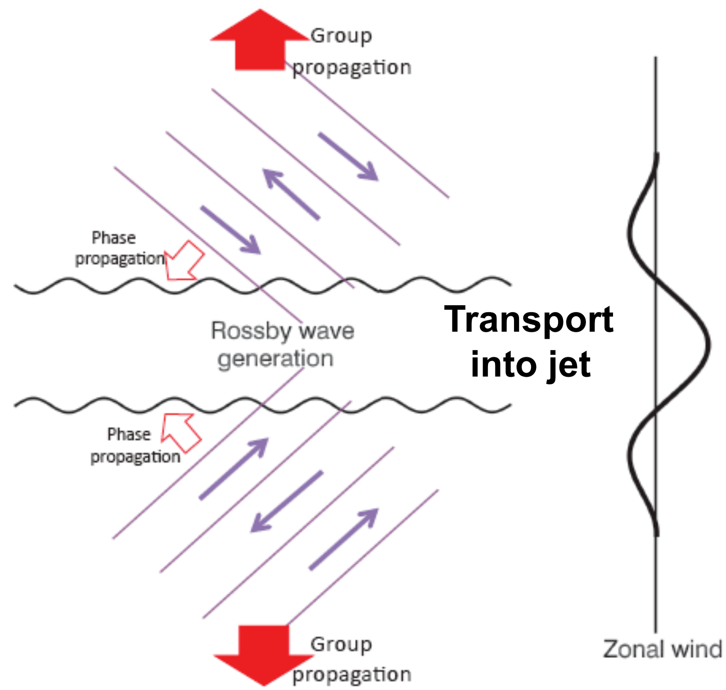
$D/L \sim f/N \quad \rightarrow \quad L_d \sim ND/f$

Rhines scale:

$d\varsigma/dy \sim \beta \quad \rightarrow \quad L_r \sim (U/\beta)^{1/2}$

Zonostrophic transition scale:

$L_\beta \sim (\varepsilon/\beta)^{1/5}$

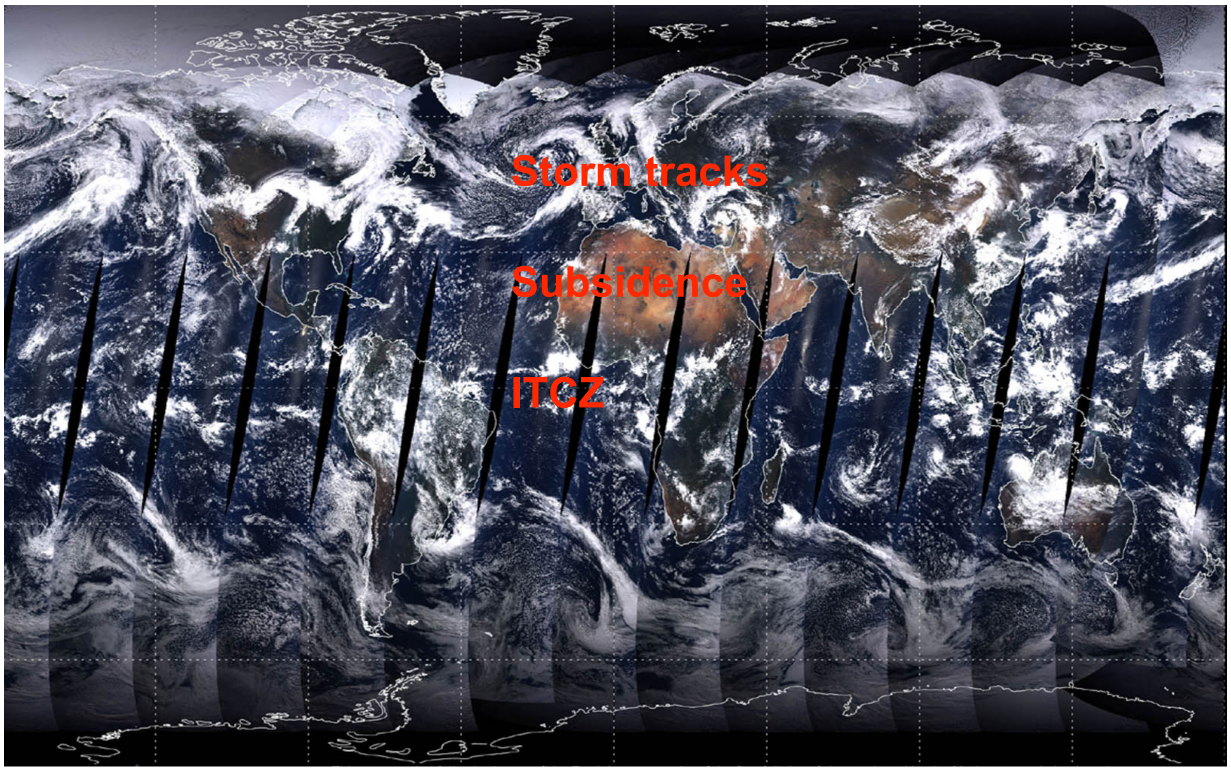


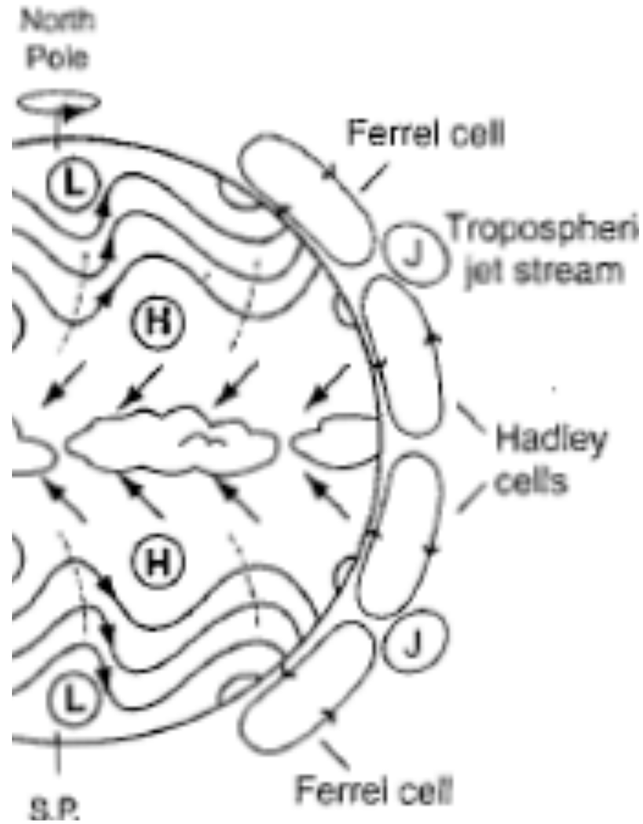
Showman et al. (2013)

Earth: $L_d \sim L_\beta \sim L_r$

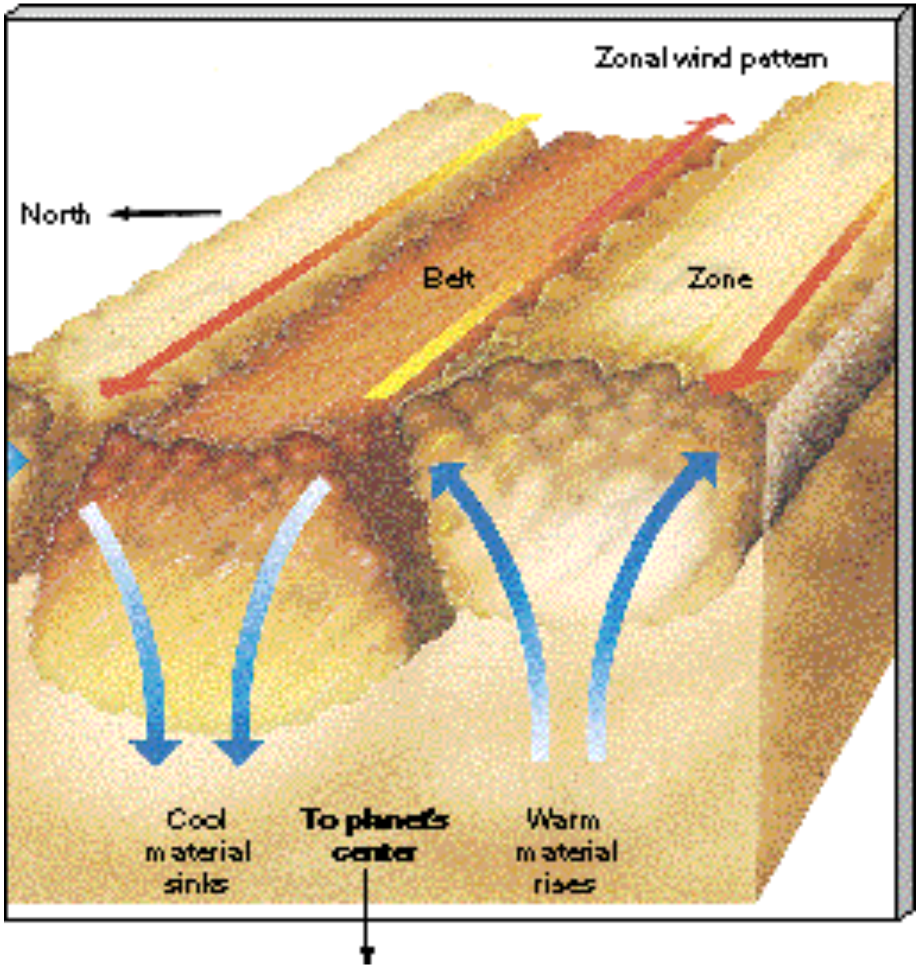
Saturn: $L_d << L_\beta << L_r$

Early observers: Bright “zones” and dark “belts” on jovian planets reminiscent of Earth’s own banded cloud structure





Gave rise to traditional view that zones and belts are analogous to Earth's tropical Hadley cell



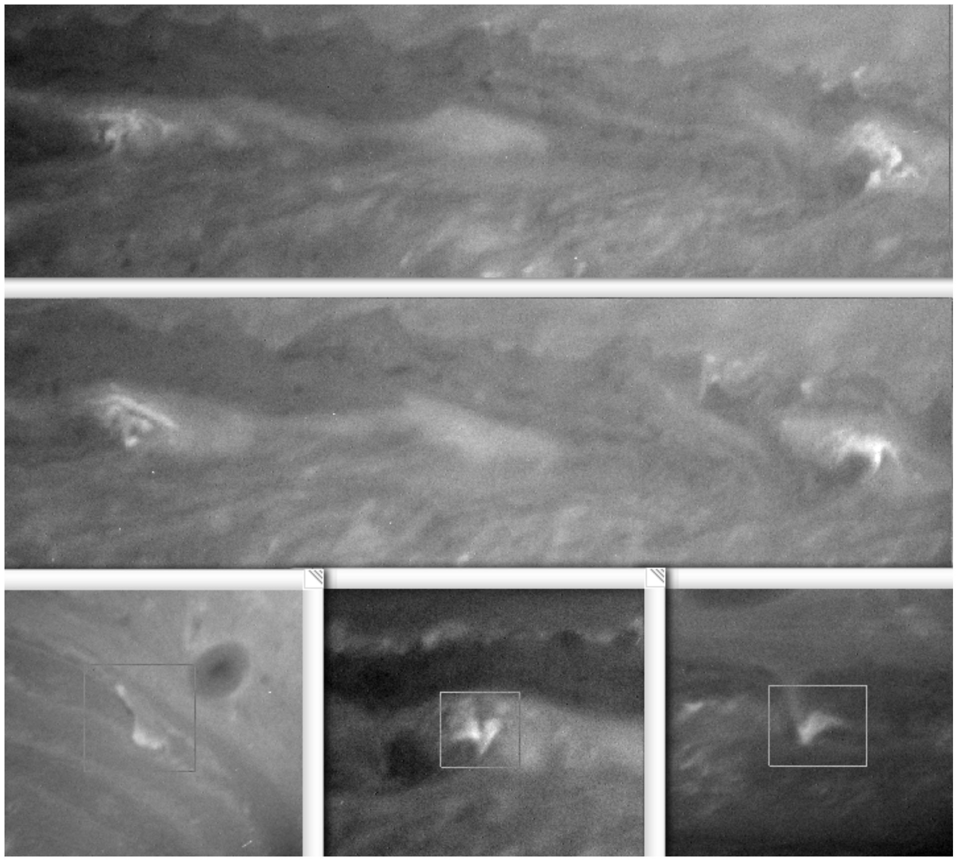
Rising in warm anti-cyclonic regions ("zones") condenses bright cloud

Sinking in cool cyclonic regions ("belts") evaporates cloud

Coriolis force on air drifting from zones to belts deflects air to right (in N.H.) and sustains eastward jets

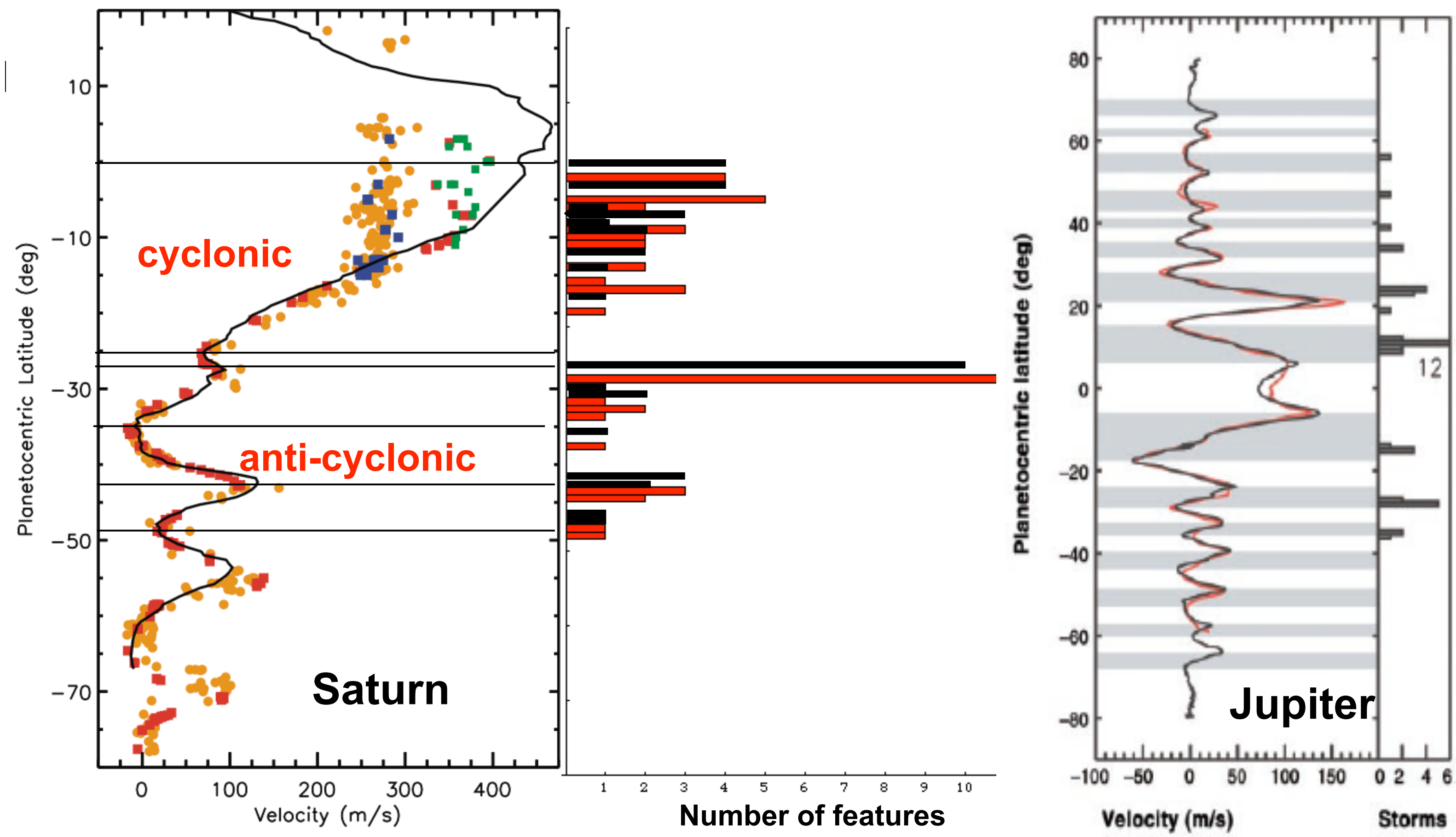
Smoking gun: Does air rise in zones and sink in belts?

Examples of Saturn convective storms



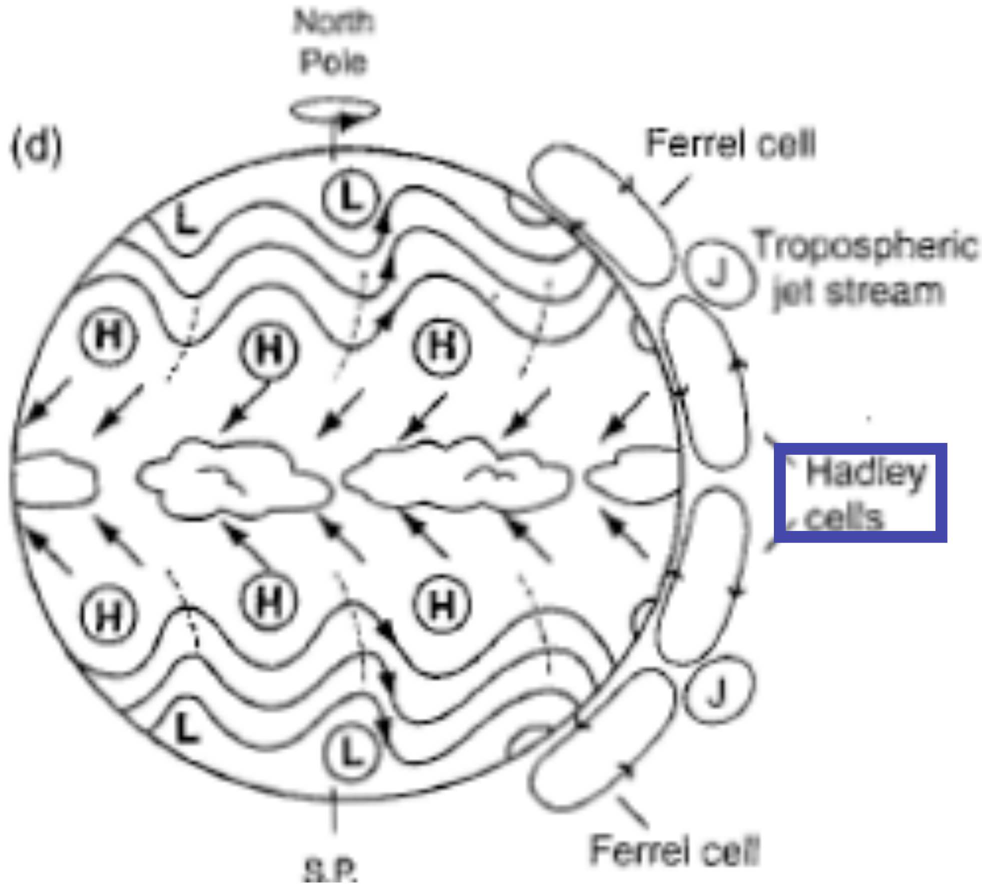
Do they occur randomly or in preferred locations?

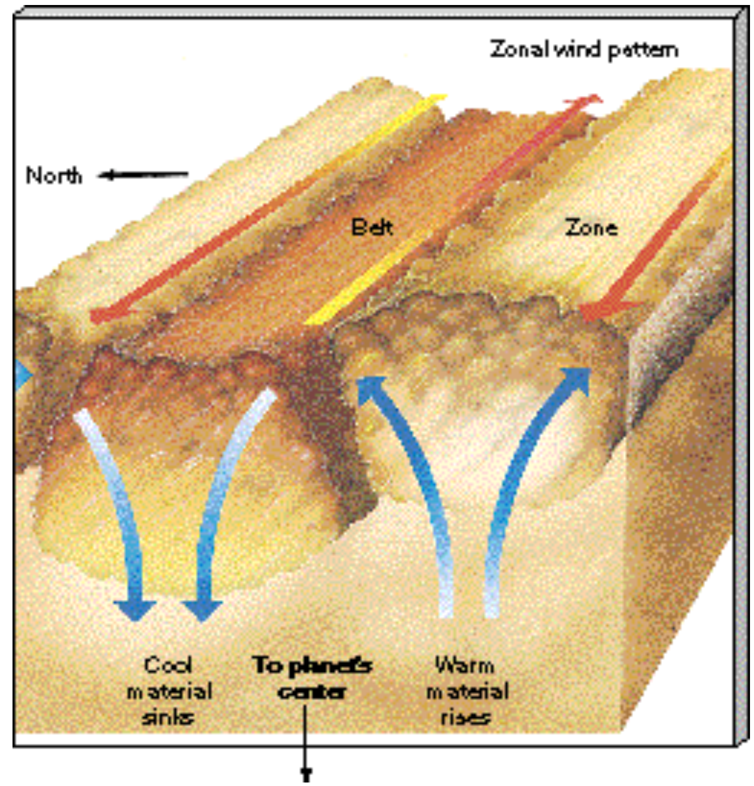
Convective features mostly in cyclonic shear ("belts"), rarely in anti-cyclonic shear ("zones") – so air rises in belts, not zones!



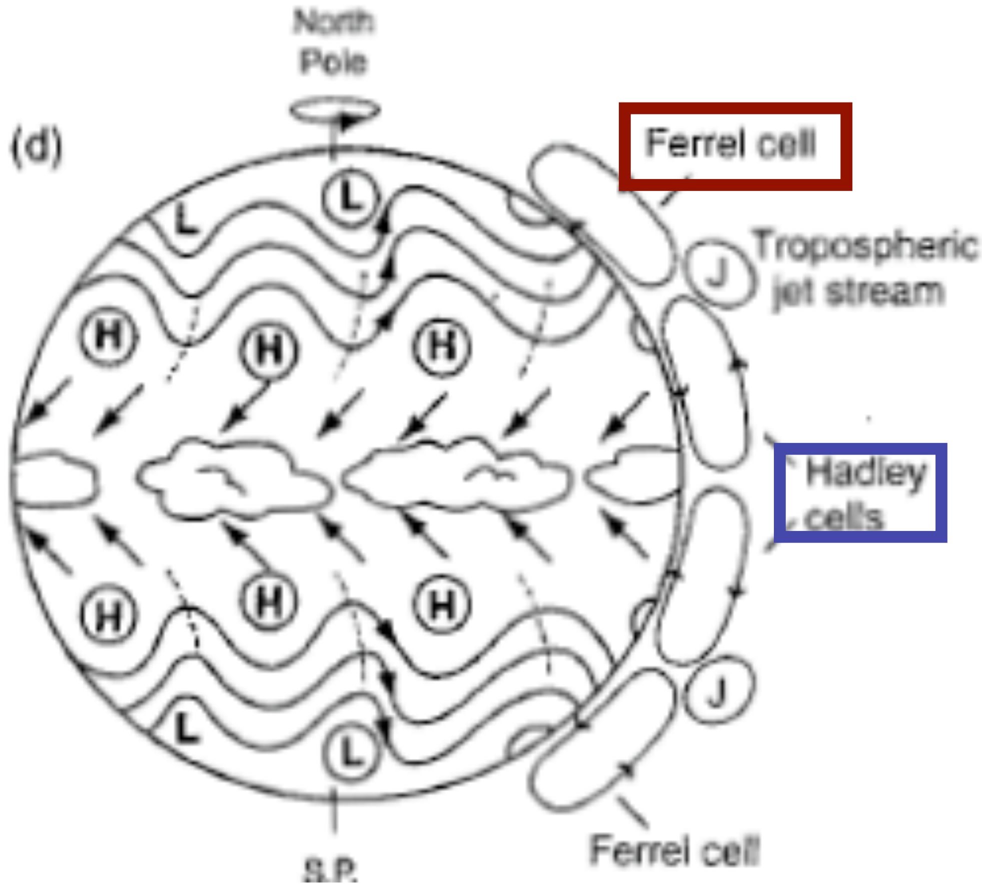
But some storms in E and W jets on Saturn, unlike Jupiter

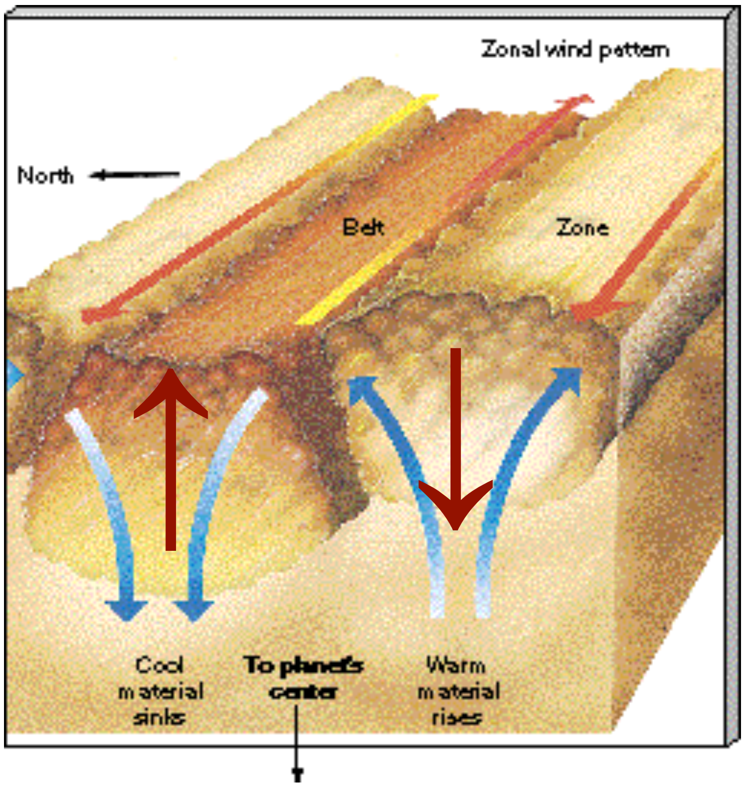
Old picture of jovian planet meteorology: Like rising/sinking branches of Earth's Hadley cell





Old picture of jovian planet meteorology: Like rising/sinking branches of Earth's Hadley cell





New picture: Like rising/sinking branches of Earth's Ferrel cell, driven by eddies…what kind?

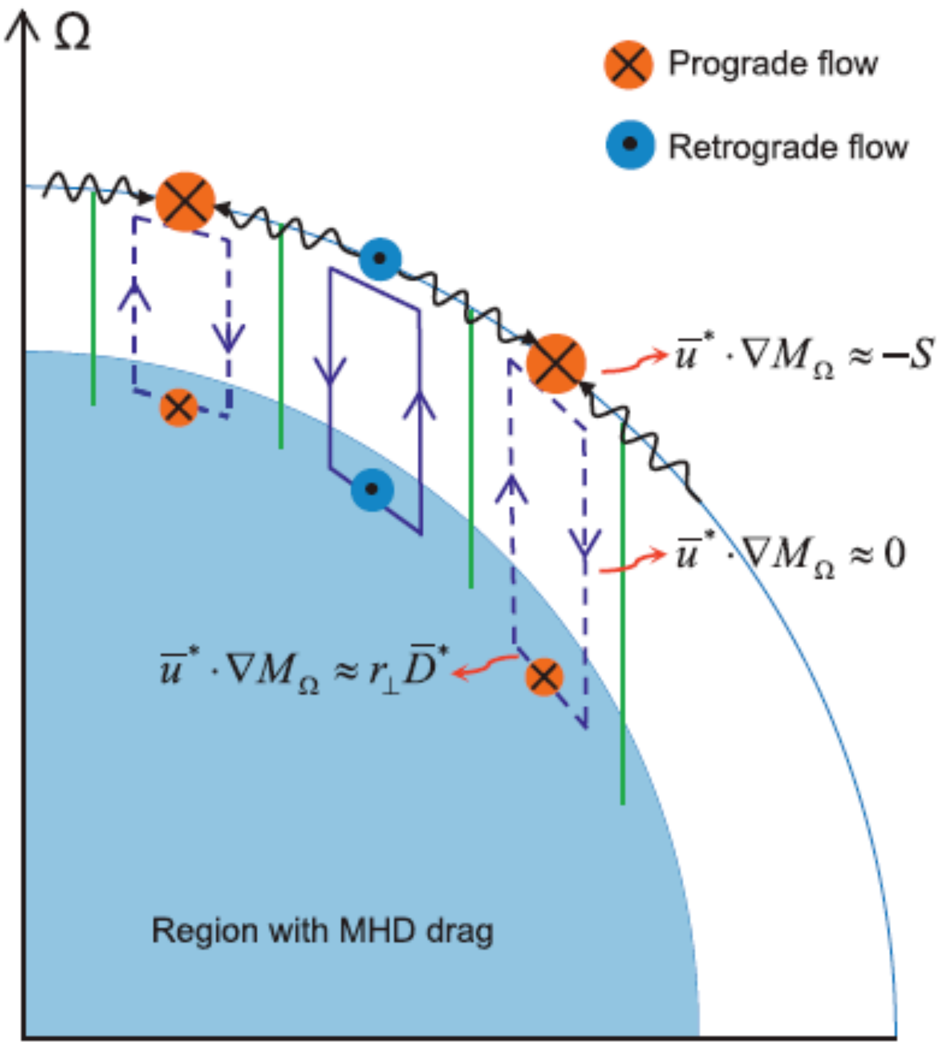


FIG. 10. Sketch of mean meridional circulation and zonal flow off the equator in giant planet atmospheres. Straight blue lines with arrows indicate the mass circulation; green lines indicate M_Ω contours; wavy lines indicate eddy angular momentum fluxes. The size of the zonal flow symbols is to suggest the speed of the flow. The blue shaded region represents the electrically conducting part of the atmosphere, where MHD drag acts.

Shallow weather layer models

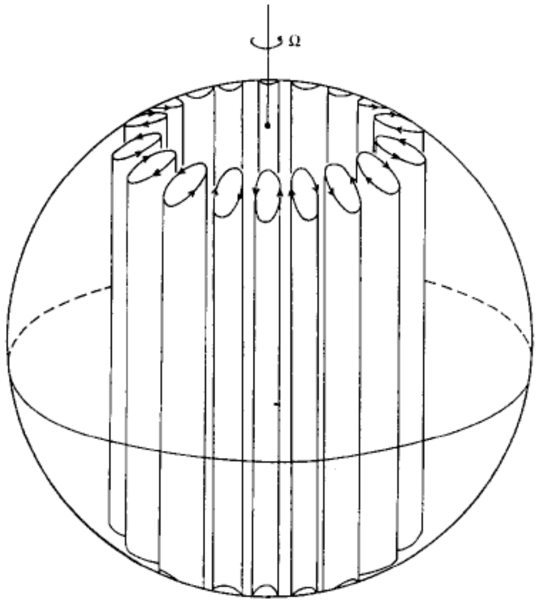
Liu and Schneider (2010): Baroclinic instability driven by solar heating, stopped below 3 bars by MHD drag; implies driving at or near MT2 level where SW is absorbed

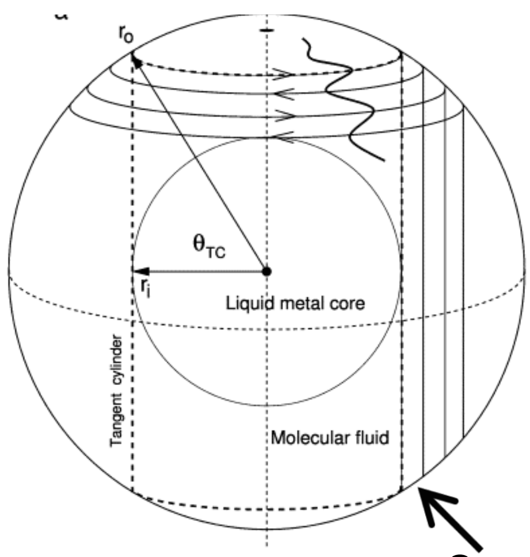
Lian and Showman (2010): Same, but driven by water condensation heating; implies driving below CB2 level where H_2O condenses

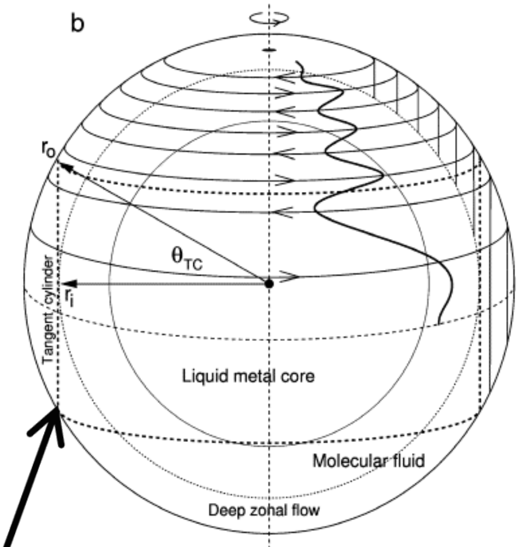
Li et al. (2006): Jet pumping by moist convection; implies eddy fluxes into jet from convection locations

Deep convective cylinder hypothesis:

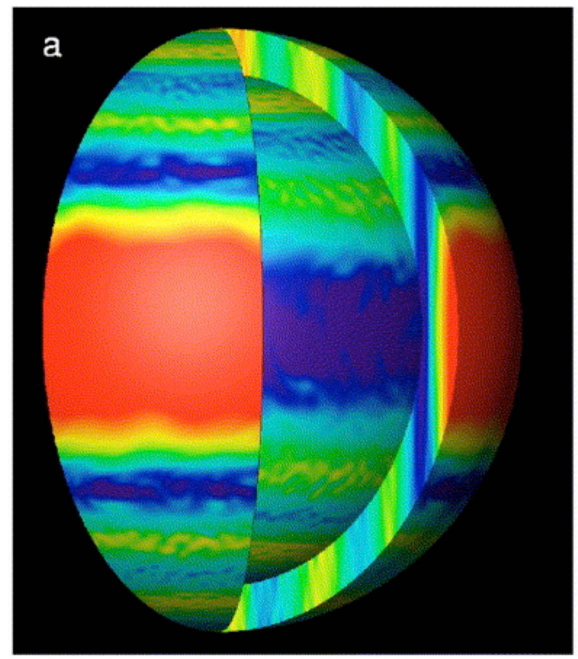
Jets are the surface manifestation of deep convective cylinders parallel to rotation axis driven directly by internal heating







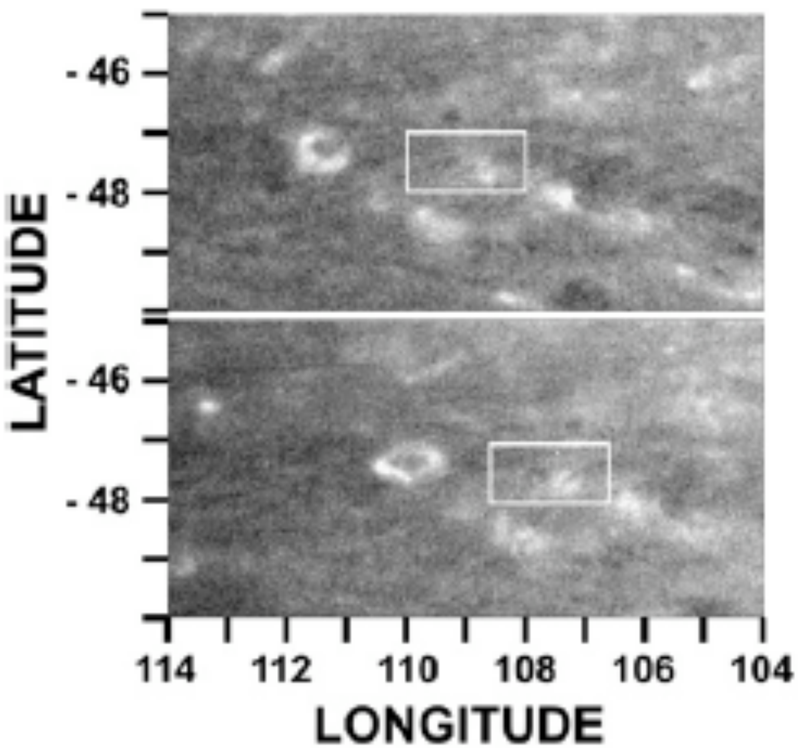
Θ_t = transition latitude

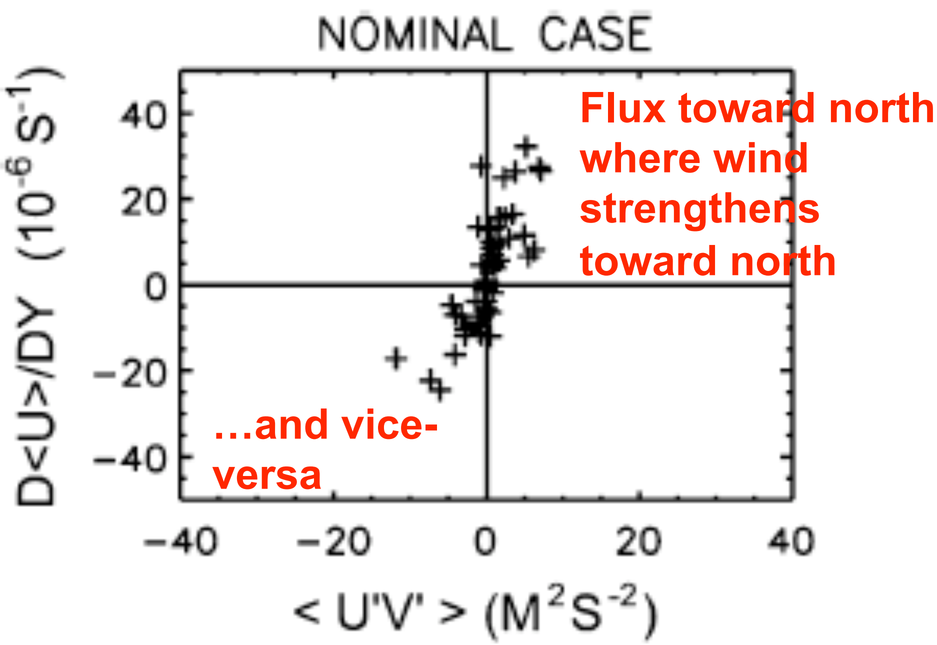


Busse (1976)

Heimpel and Aurnou (2007)

ID same feature in images on successive orbits using automated algorithm, measure departures of wind speed from mean in east-west (u') and north-south (v') directions: Are they correlated? If so, only at certain latitudes?

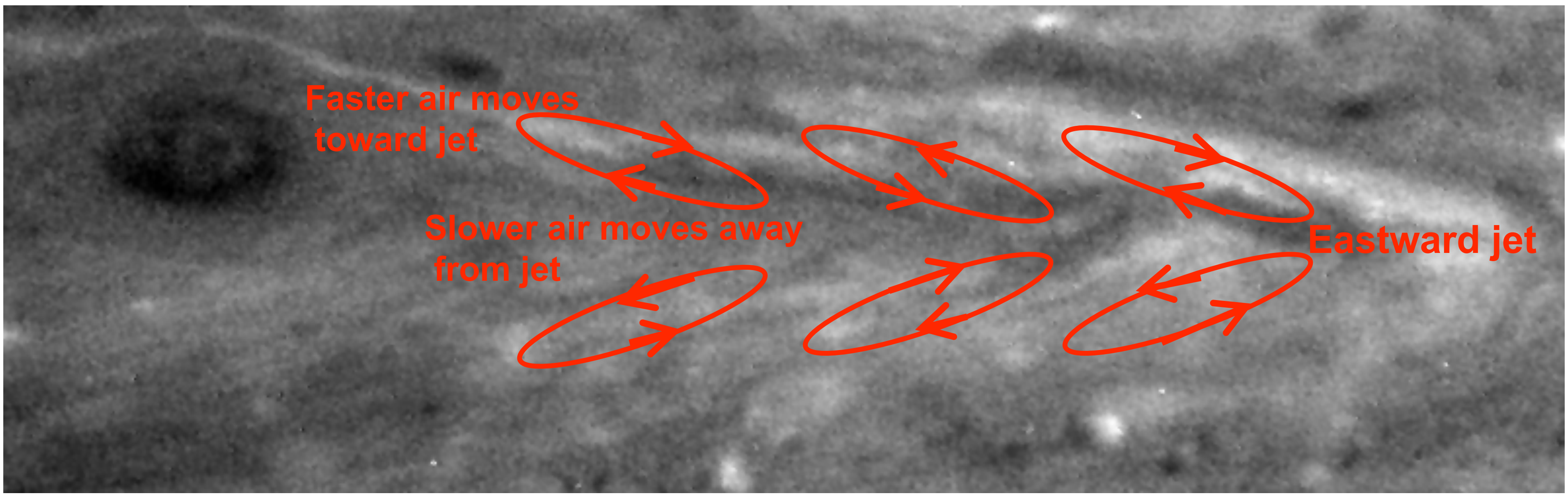




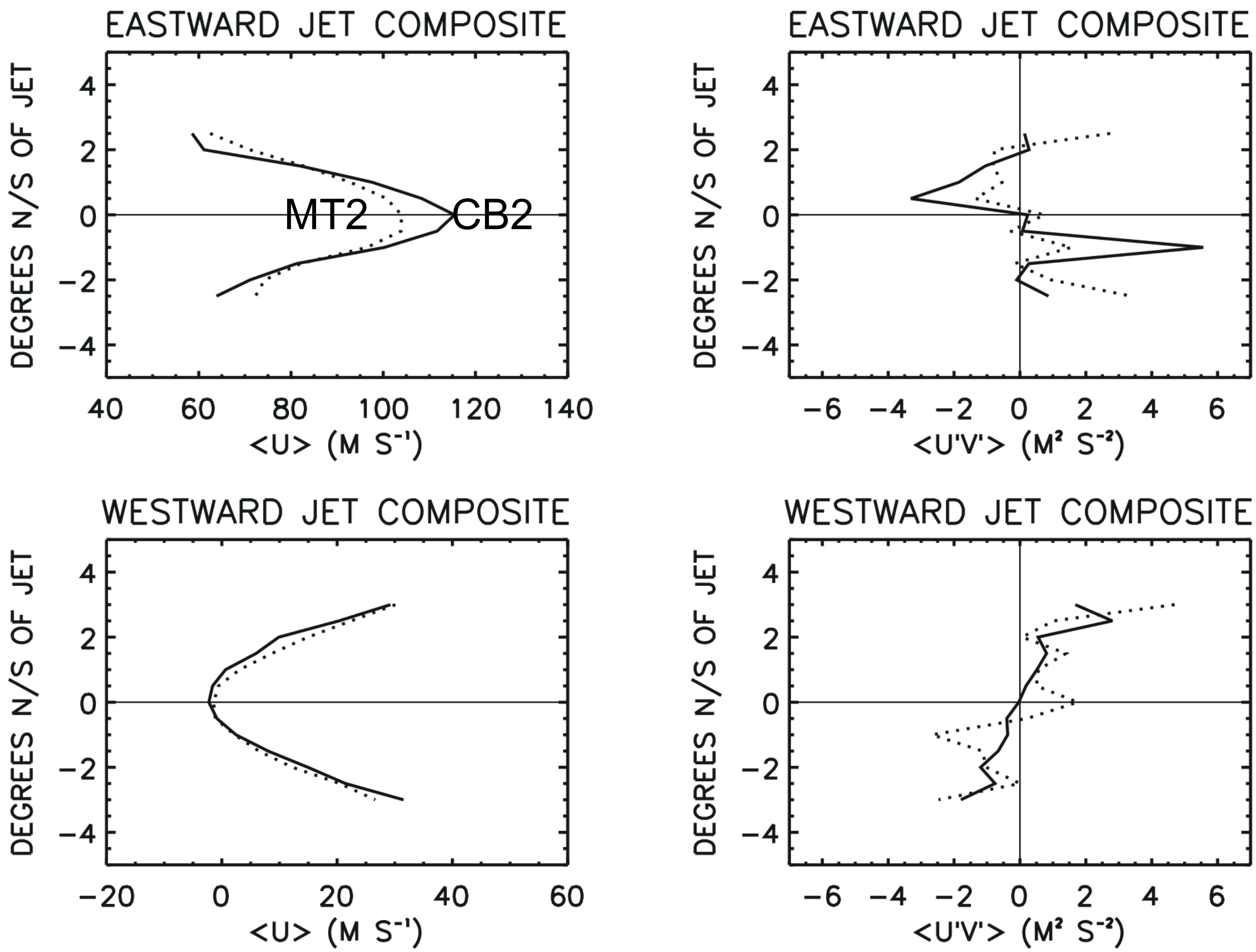
Implies that kinetic energy of eddies is being converted to kinetic energy of mean flow in the jet everywhere

Tilted eddies carry higher-than-average momentum air into jet, and lower-than-average momentum air out of the jet, which accelerates it

Like midlatitude baroclinic storms on Earth



Flux on both sides of jet rules out direct convective pumping mechanism



- **Eastward jets weaken, broaden with height; westward jets do not**
- **Eddy flux convergence into jet also weakens upward (east jets only)**
- **Consistent with jet driving process at or below cloud level**

Scorecard on jet maintenance mechanisms:

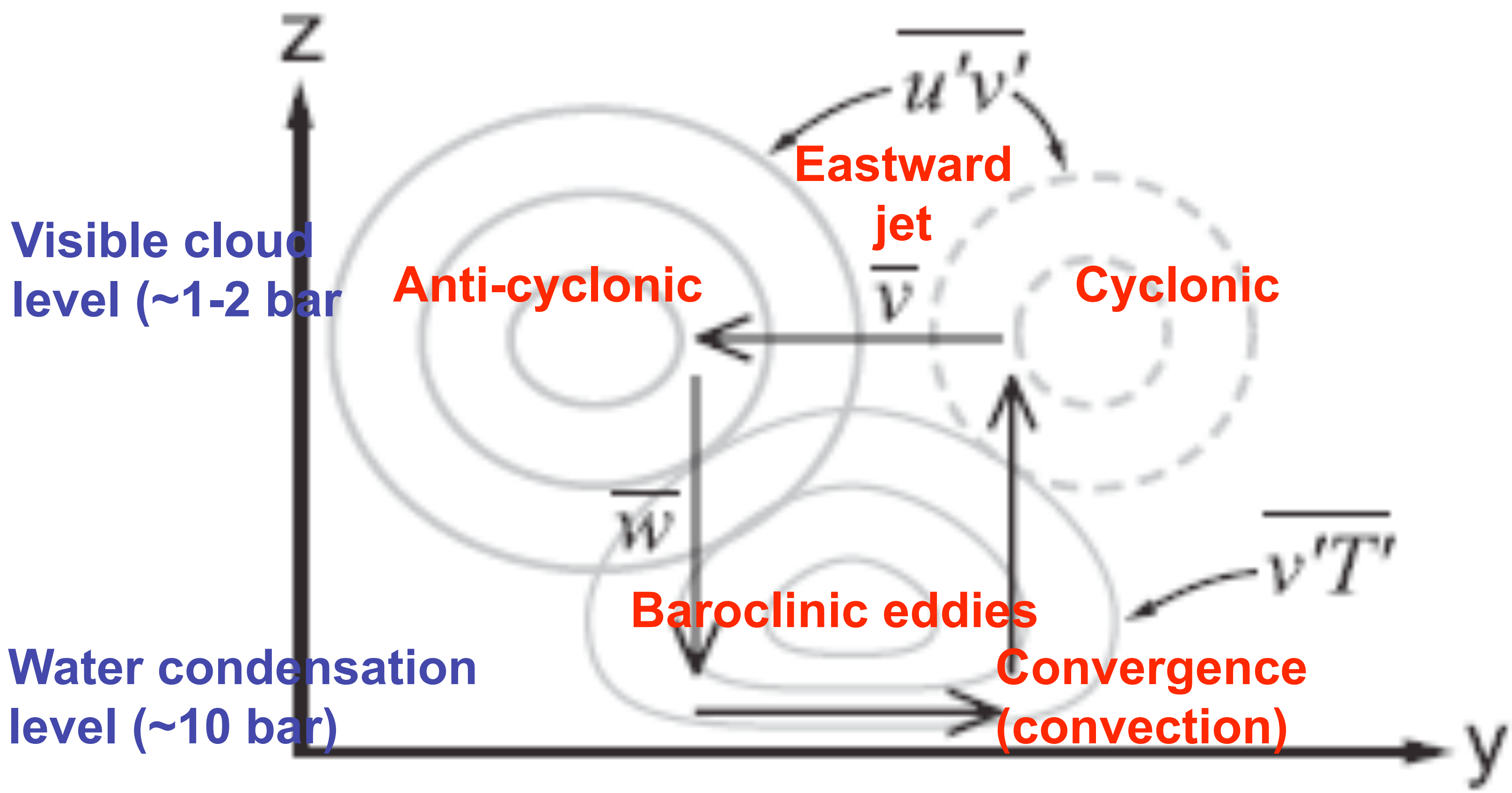
Coriolis force on poleward-drifting air associated with cells of rising-sinking motion (like Earth tropics) – inconsistent with convection in belts rather than zones

Baroclinic instability (like Earth high-low pressure centers) due to latitudinal temperature differences – consistent with eddy momentum flux into jet from both sides and rising motion in belts, but only if driven by latent rather than radiative heating

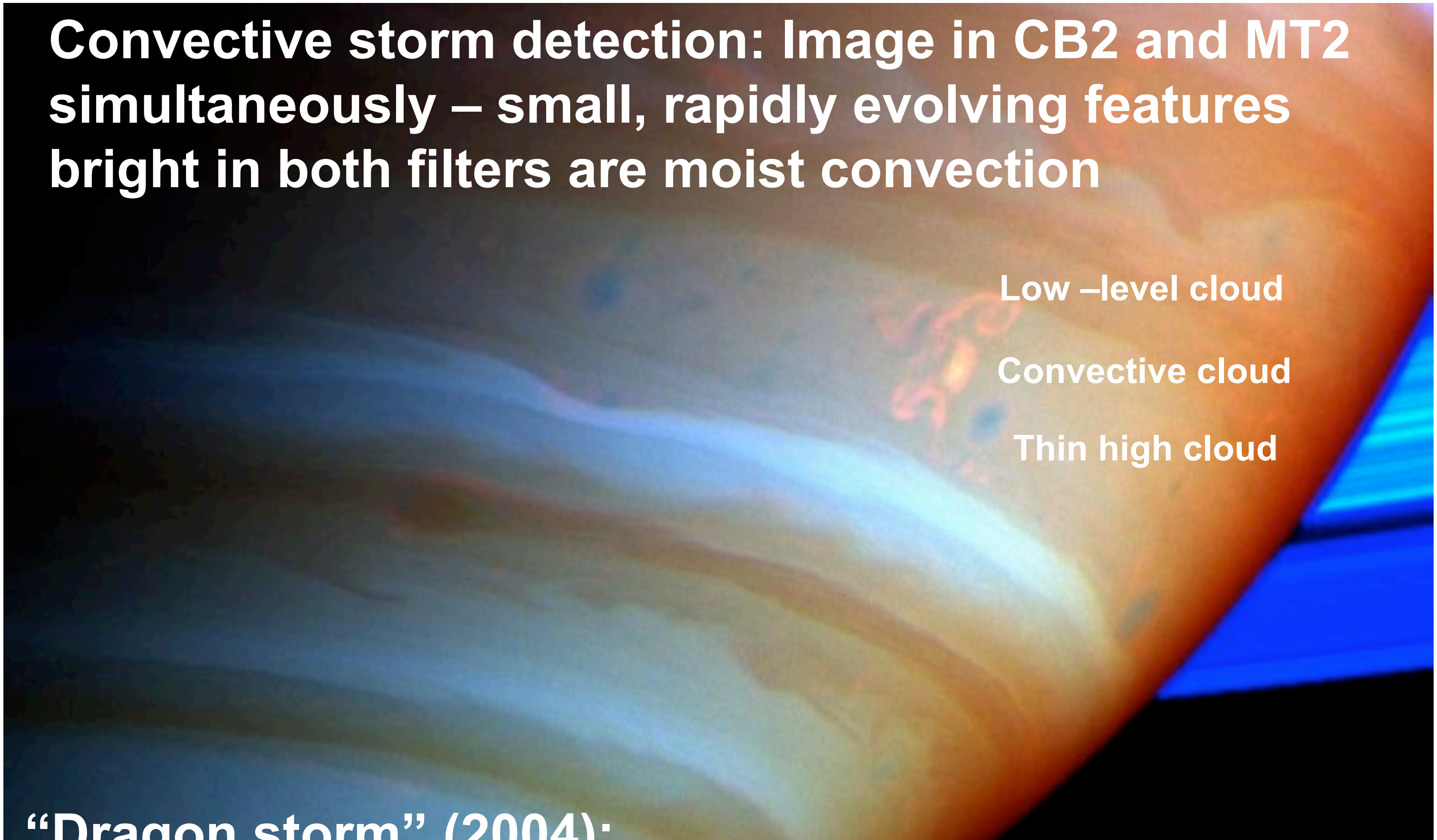
Pumping by thunderstorms feeds energy into jets – no evidence for special behavior near storms, inconsistent with eddy momentum flux on both sides of jets

Cloud-level manifestation of deep rotating convective cylinders – TBD, but see discussion to follow

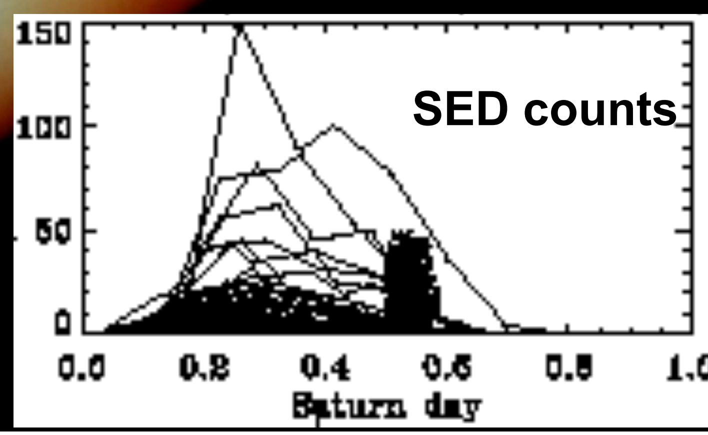
Latitudinal cross-section of Earth's general circulation (Hartmann, 2008) – valid for Jupiter and Saturn too?

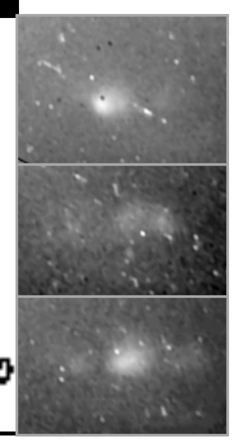


Convective storm detection: Image in CB2 and MT2 simultaneously – small, rapidly evolving features bright in both filters are moist convection



“Dragon storm” (2004): appearance at 35°S correlates with Saturn electrostatic discharges; again in 2006, this time with nightside lightning detected





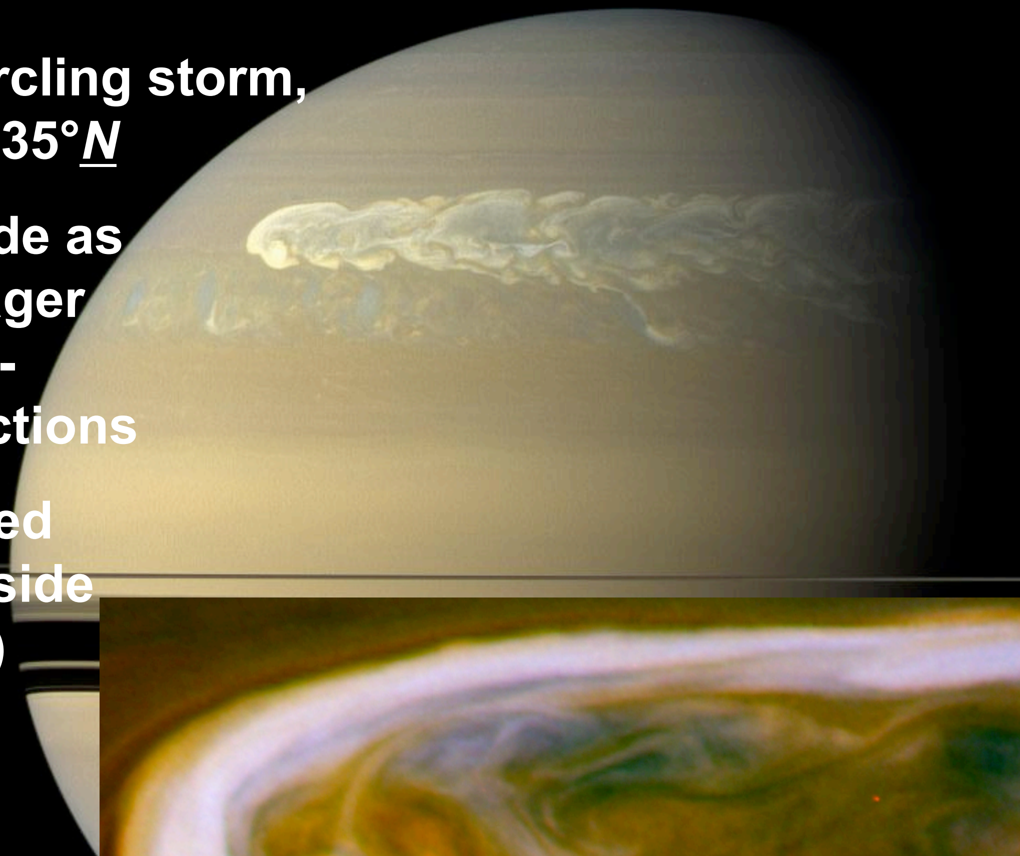
Dec. 2010-June 2011:

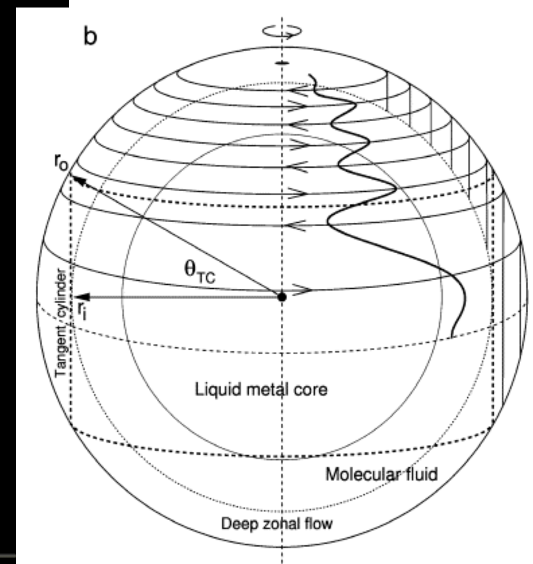
Planet-encircling storm, this time at 35°***N***

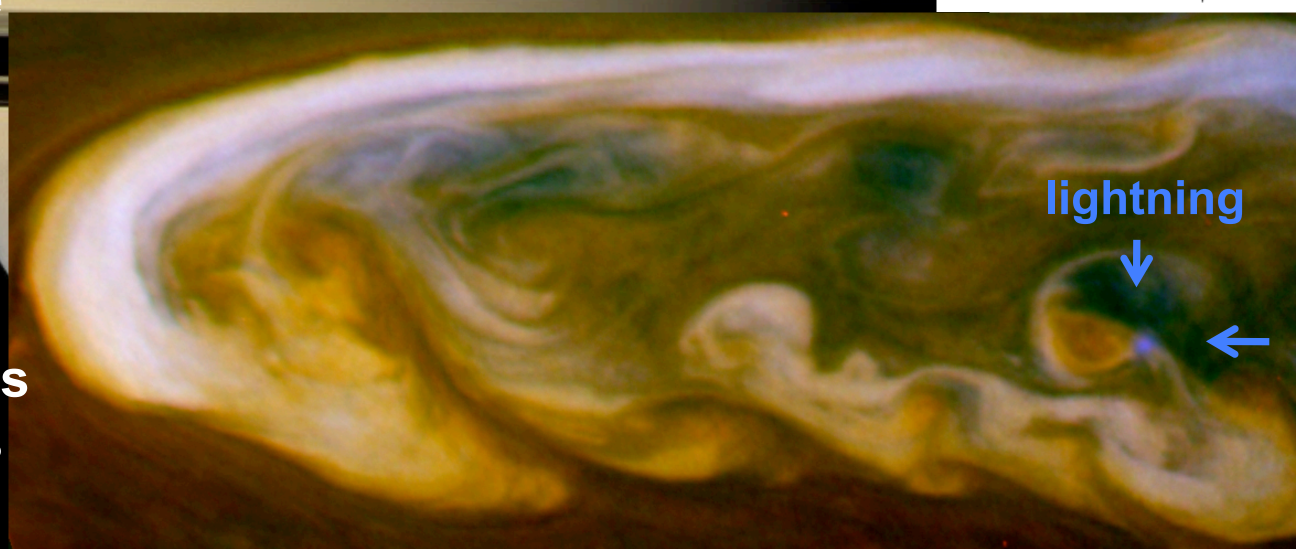
Same latitude as earlier Voyager and ground-based detections

Accompanied by first dayside (coincident) lightning detection

Do the major storm outbreaks mark the edges of the deep cylinders?







(courtesy U. Dyudina)

Conclusions

- General circulation of the jovian planets may indeed be an analogy to Earth…but to Earth's midlatitudes rather than its tropics
- Multiple jets on jovian planets a consequence of their rapid rotation and large size, reflecting the distance over which Rossby waves modify flow
- Wind-albedo relationship on Saturn yet to be understood; complicated by thick upper level haze
- Dramatic long-lived convective storms have formed preferentially on Saturn only in 2 places in the 9 years of Cassini – 35°S, 35°N; a tracer somehow of a transition between deep and shallow weather regimes?


You are here →